



Lecture 3

The Stack. Buffer Management

Computer and Network Security

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Computer Science and Engineering Department

- ▶ inspect processes
- ▶ inspect resources: file, sockets, IPC (lsof, netstat, ss)
- ▶ inspect memory: pmap, GDB
- ▶ inspect calls: strace, ltrace
- ▶ thorough inspection: in debuggers (GDB, Immunity, OllyDbg)

- ▶ attack vulnerabilities in process address space and process flow
- ▶ attacker aims
 - ▶ get a shell
 - ▶ privilege escalation
 - ▶ information leak
 - ▶ denial of service
- ▶ defender: hardening process and runtime environment (libraries, permissions, sandboxing, monitoring)

- ▶ thread and process management
- ▶ (virtual) memory management
- ▶ intimate information on the process address space
- ▶ working with arrays and strings
- ▶ hex/binary
- ▶ assembly, disassembling
- ▶ platform ISA
- ▶ good skills working with a debugger

- ▶ memory address space of a process
- ▶ linear
- ▶ memory areas, responsibilities
- ▶ static/dynamic allocation
- ▶ memory mapping
- ▶ access rights

- ▶ stores code
- ▶ read only and executable
- ▶ instruction pointer/program counter points to current instruction
- ▶ libraries posses code segment
- ▶ instruction pointer may jump to library code

- ▶ stores data (global variables)
- ▶ `.data`, `.bss`, `.rodata`
- ▶ read-write, `.rodata` is read-only
- ▶ accessed through normal registers (`eax`, `ebx`, `ecx`, `edx`)

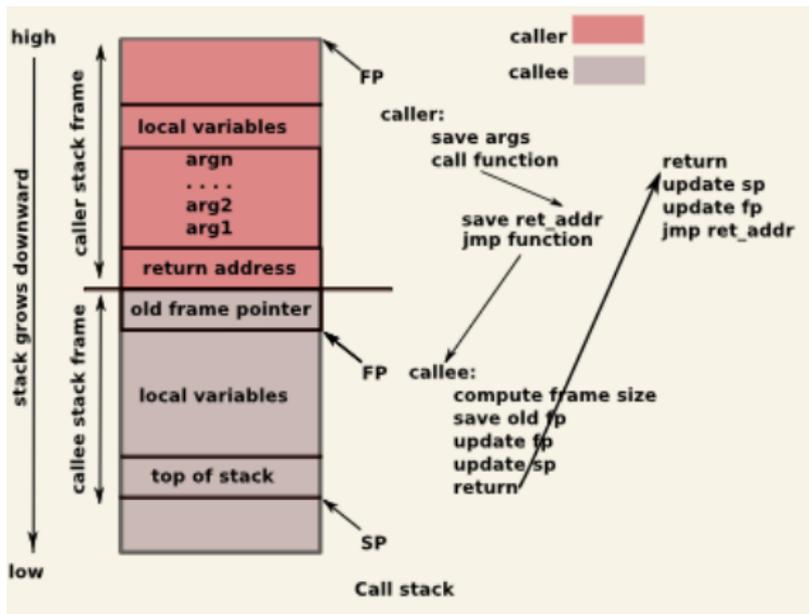
- ▶ dynamic memory allocation
- ▶ malloc and friends
- ▶ linked list implementation in the backend
- ▶ pointer madness
- ▶ memory leaks
- ▶ read-write

- ▶ store function call frames
- ▶ function arguments and local variables
- ▶ stack pointer, frame pointer
- ▶ read-write

- ▶ push: push new element on stack
- ▶ pop: pop element on stack, return `null` if no element on stack
- ▶ top/peek: show last element on stack
- ▶ can only push to top and pop from top of the stack

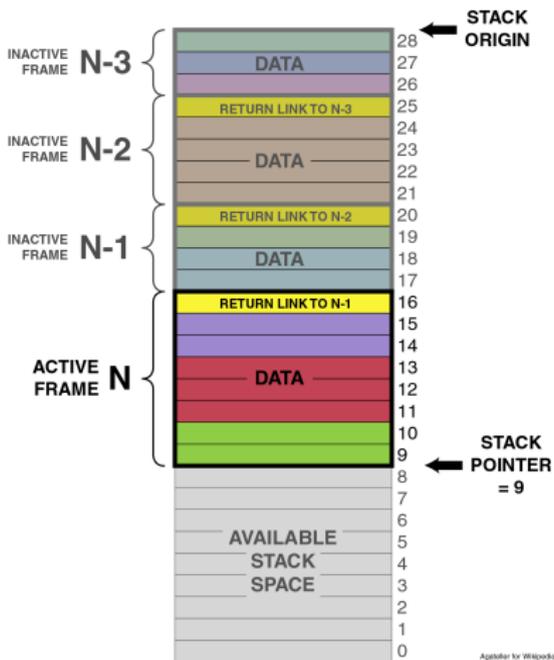
- ▶ it's bottom up in x86 architecture
- ▶ base address points to bottom of the stack
- ▶ stack pointer points to top of the stack
- ▶ stack pointer \leq base address
- ▶ stack size = base_address - stack pointer
- ▶ stack "grows down"
 - ▶ when stack grows, stack pointer decreases in value
 - ▶ when stack decreases, stack pointer increases in value

- ▶ push operation adds data to stack: stack grows, stack pointer decreases
- ▶ push is equivalent to
 - ▶ `sub $4, %esp`
 - ▶ `mov value, (%esp)`
- ▶ pop operation removes data from stack: stack decreases, stack pointer increases
- ▶ push is equivalent to
 - ▶ `mov (%esp), value`
 - ▶ `add $4, %esp`



<http://ocw.cs.pub.ro/courses/so/laboratoare/laborator-04>

- ▶ caller and callee
- ▶ stores current function call context
- ▶ stores return address
- ▶ identified by frame pointer
- ▶ What does the `-fomit-frame-pointer` option do?
- ▶ call stack
- ▶ stack (back)trace



[http://en.wikipedia.org/wiki/Stack_\(abstract_data_type\)#Hardware_stacks](http://en.wikipedia.org/wiki/Stack_(abstract_data_type)#Hardware_stacks)

- ▶ push function arguments, stack pointer decreases, the stack grows
- ▶ issue `call new-function-address`
 - ▶ save/push instruction pointer on stack (stack grows, stack pointer decreases)
 - ▶ jump to `new-function-address`
- ▶ save/push old frame pointer
- ▶ save current stack pointer in frame pointer register
- ▶ save registers
- ▶ make room on stack (stack grows, stack pointer decreases)

- ▶ discard stack (stack decreases, stack pointer increases)
- ▶ restore/pop registers
- ▶ restore/pop old frame pointer
- ▶ issue `ret`
 - ▶ restore instruction pointer from top of the stack (stack decreases, stack pointer increases)
 - ▶ continue execution from previous point
- ▶ restore frame pointer
- ▶ discard stack in caller frame

- ▶ an array of bytes for storing temporary data
- ▶ generally dynamic (its contents change during runtime)
- ▶ frequent access: read-write
- ▶ base address, data type, number of elements
- ▶ $\text{buffer size} = \text{number of elements} * \text{sizeof}(\text{data type})$

- ▶ store data during runtime
- ▶ pass data between functions (arguments or return values)

- ▶ static allocation: at compile time (in data or bss)
- ▶ dynamic allocation: at runtime (`malloc`, on heap)
- ▶ automatic allocation: on the stack, during runtime, usually fixed size
- ▶ in case of dynamic allocation, the pointer variable is stored on the stack and the actual buffer data is stored on the heap
- ▶ allocation granularity is the page at OS/hardware-level

- ▶ `int buffer[10];` – array
- ▶ `int *buffer;` – pointer
- ▶ array occupies `sizeof(buffer)`
- ▶ pointer occupies `sizeof(int *) + size_of_buffer`
- ▶ an array is like a label
- ▶ a pointer is a variable

- ▶ you have to know their length
 - ▶ buffer overflow
- ▶ you have to be careful about the index
 - ▶ index out of bounds
 - ▶ buffer overflow
 - ▶ negative index

- ▶ write data continuously in buffer (strcpy-like)
- ▶ pass buffer boundary and overwrite data
- ▶ may be exploited by writing function pointers, return address or function pointers
- ▶ allocations is page level, so overflow won't trigger exceptions
- ▶ may be stack-based or heap-based

- ▶ not enough arguments for a function call
- ▶ too many arguments for a function call
- ▶ overflow of local buffers

- ▶ stored on the stack to allow jump back
- ▶ may be overwritten and allow random jumps (the stack is read write)

- ▶ the stack overflows, goes into another memory zone
- ▶ may be the heap
- ▶ may be another stack in case of a multithreaded program

- ▶ overflow buffer on stack and rewrite something
- ▶ rewriting may be a local variable (number, function pointer) or return address of current stack frame
- ▶ if rewriting a function pointer jump to a convenient address: address of buffer on stack, address of environment variable, address of function in libc

- ▶ the usual way to exploit a stack buffer overflow (needs non-executable stack)
- ▶ do a stack buffer overflow and overwrite the return address ($ebp+4$)
- ▶ overwrite with start address of buffer on the stack
- ▶ when function returns, jump to start address of buffer
- ▶ carefully place instructions to execute desired code at the beginning of the buffer (also dubbed shellcode)

- ▶ buffer may be placed at non-exact address
- ▶ one solution is guessing the address
- ▶ the other is placing a sufficient number of NOP operations and jump to an address in the middle of the NOPs
- ▶ the program executes a set of NOPs and then reaches the actual shellcode

- ▶ a sequence of instructions allowing the execution of an instruction similar to `system("/bin/sh");`
- ▶ usually provides a shell out of an average program
- ▶ may do some other actions (reading files, writing to files)
- ▶ the shell is a first step of an exploitation
- ▶ followed by an attempt to gain root access
- ▶ more on “Lecture 03: Exploiting”

- ▶ jump to a function call in the C library (such as system or exec)
- ▶ may be used in heap or data segments
- ▶ useful when stack is non-executable

- ▶ the stack in shellcodes
- ▶ level 5 from io.smashthestack.org

- ▶ address space
- ▶ stack
- ▶ push
- ▶ pop
- ▶ stack frame
- ▶ call stack
- ▶ stack trace
- ▶ call
- ▶ ret
- ▶ buffer
- ▶ allocation
- ▶ buffer overflow
- ▶ return address
- ▶ NOP sled
- ▶ shellcode

- ▶ Aleph One – Smashing the Stack for Fun and Profit:
<http://insecure.org/stf/smashstack.html>
- ▶ <http://www.cs.umd.edu/class/sum2003/cmsc311/Notes/Mips/stack.html>
- ▶ <http://www.cs.vu.nl/~herbertb/misc/bufferoverflow/>
- ▶ <http://www.win.tue.nl/~aeb/linux/hh/hh-10.html>

- ▶ Security Warrior
 - ▶ Chapter 5. Overflow Attacks
- ▶ The Ethical Hacker's Handbook, 3rd Edition
 - ▶ Chapter 11: Basic Linux Exploits
- ▶ The Art of Exploitation, 2nd Edition
 - ▶ Section 0x270. Memory Segmentation
 - ▶ Chapter 0x300. Exploitation